Dynamic measurements as a control for offshore piling

Mesures dynamiques pour le contrôle des pieux offshore

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SYNOPSIS Extensive dynamic pile driving instrumentation has been used by Petrobras as a control for offshore platform piling. The total number of structures tested to date is 15, with the water depth varying from 16m to 170m and the penetration of the pile varying from 20m to 145m below mudline. The main oil production fields, where the testing was performed, are in the north-east and in the south of the Brazil.

From dynamic measurements of force and acceleration near the pile top, information was obtained, such as the different hammer performances and the bearing capacity estimates.

Some aspects of the calcareous soil, that occur along the Brazilian Continental Shelf are discussed, specially their behaviour during the driving and set-up factor in different fields.

INTRODUCTION

Since 1980, as a part of the offshore platform piling control procedure, dynamic measurements during the driving have been used by Petrobrás. The first one was at the Garoupa platform in the Campos Basin, whose instrumentation was conducted by DnV (Det norske Veritas). After this, a special full-scale driveability testing was carried out by IPT (Instituto de Pesquisas Tecnológicas) and PDI (Pile Dynamics Inc.) in the Curimã field, close to the existing platform PCR-2. Subsequently, other platforms were instrumented as showed in Table I, where the variation of the water depth and the pile penetration below mudline are observed. The schematic location is showed in Fig. 1.

Fig. 1 - Schematic Location of the Fields

CHARACTERISTICS OF THE SOIL IN DIFFERENT FIELDS

Along the Brazilian Coast, the soil profile presents a certain predominance of the calcareous soils. This paper considers two basic regions: the north-east region and the Campos Basin, located on the south part of the country (Fig. 1).

TABLE I

Offshore Platform Piling Instrumented Since 1980

FIELD	PLATFORM	TESTING BY	WATER DEPTH (m)	MAXIMUM PENETRAT. (m)	NUMBER OF TESTED PILES
GAROUPA	PGP-1	DNV	120	87	4
ENCHOVA	PCE-1	GEO/WCC	116	89	6
NAMORADO	PNA-1	GEO/WCC	146	116	3
	PNA-2	AAN/IPT	170	114	5
CHERNE	PCH-1	AAN/IPT	117	102	2
	PCH-2	FRA/FUG	142	110	4
PAMPO	PPM-1	AAN/IPT	110	87	6
CURIMA	CLOSE/PCR-2	IPT/PDI	52	90	1
	PCR-1	IPT	52	95	15
ATUM	GRID/PAT-2	IPT	55	59	2
	PAT-1	IPT	55	80	8
	PAT-2	IPT	55	80	8
UBARANA	PUB-8	IPT	16	19	2
	PUB-9	IPT	16	19	8
CAIOBA	PCB-4	IPT	27	70	4

NOTE: DNV - DET NORSKE VERITAS; GEO - GEOTECNICA; WCC - WOODWARD-CLYDE CONS.; AAN - ANTONIO A. NORONHA; FRA - FRANKI; FUG - FUGRO; IPT - INST. PESQ. TECN.; PDI - PILE DYNAMICS INC.

North-East Region

In this region there are many oil producing fields, with water depth varying from 16m (proximity of Ubarana field) to 55m (other fields). Figure 2-a shows some soil profiles related to the instrumented platforms.

One of the difficulties to the foundation design in this area is related to the evaluation of the soil properties, when the soil presents a high carbonate contents.

In the Curimã field a strong cementation of the calcareous soils was observed, besides considerable coral layers and caverns encountered along the depth. During the driving it was observed continuous degradation of the unit skin friction calculated by CAPWAP analysis carried out at different penetration. This effect was attributed to the crushibility of the cemented calcareous sand (Niyama et al, 1984).

In the Ubarana field, the presence of the strongly cemented calcareous soils at shallow depth (approximately 20m below seafloor) has been considered as the main problem to driven piles. In general, due to the high blow count verified in this stratum, the final pile penetration was less than required by design in view of the significant pull-out load. In those cases, the dynamic measurements led to the strengthening solution.

Campos Basin

The Campos Basin is characterized by oil production structures located in deep waters varying from 110m to roughly 200m. Some of the soil profiles in this area are showed in Figure 2-b, where a complex stratigraphy is observed. Basically, the typical profile is composed by shallow layer of calcareous sand/silt near the sea floor followed by sandy silts and silty clays intermixed with sand layers and shell frangments.

In the South Pole (location of the PCE-1/PPM-1 platform) the pile are supported by the cemented sand layers. In the North Pole, except close to PGP-1/PCH-1 fields, the cohesive soil are prevalent and then, the piles are of floating type, supported practically by skin friction resistance.

Set-Up Effect

One of the main objetives of the instrumentation is the evaluation of the set-up effect of the soils, fundamental parameter to estimate long-term bearing capacity. In some cases, it is possible to conduct ideal redriving program to take set--up factor at various periods after the initial driving. In Fig. 3, three cases of the set-up trends, obtained from redrivings made after up to 87 days, are presented. Note that this figure shows the set-up period versus gain of the mobilized skin friction resistance obtained from CAPWAP analysis. The driving resistance during the redrive conditions after a set-up time of approximately 60 to 70 days indicates a set-up factor of 3 to 4 (Ping et al, 1984) at the Enchova/Namorado field (Campos Basin). Similar value of set-up factor was verified in the Curimã field.

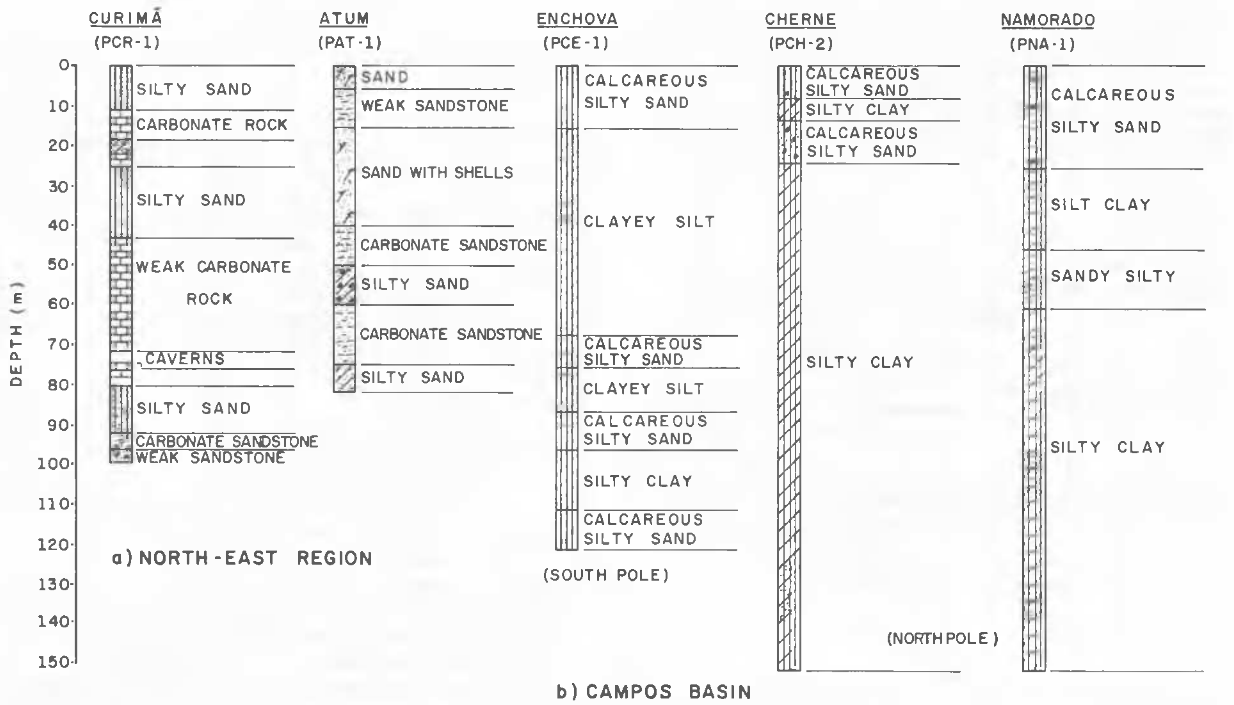

Fig. 2 - Simplified Soil Profiles at Different Fields

Microscopic Analysis

In view of the international tendency to study calcareous soils under some aspects, in laboratory, using scanning electron microscope (SEM), two microphotos of specimens prepared from samples obtained in the boring carried out close to PCR-1 platform, at 63m depth (Sample A) and 93m depth (Sample B), are presented in the Fig. 4 and Fig. 5. The identification of the carbonate mineral by X-ray diffraction analysis revealed calcite in the sample A and dolomite in the Sample B. According to petrographic classification, Sample A was classified as algalic microsparitic limestone and Sample B as algalic very fine cristaline dolomite.

The Fig. 4 shows the preponderant part of specimen (90% to 95%) composed by allochemical components (Rodophitas). The Fig. 5 shows the neomorphic carbonate matrix (80%) involving quartz particles.

This kind of descriptive analysis intend to be the initial phase for a study into the nature and engineering behavior of the Brazilian carbonate soils.

INSTRUMENTATION

As showed in Table I, different contractors carried out dynamic measurements and, basically, in most of the cases both instrumentation and processing methods originally developed at Case Western Reserve University were used. Two accelerometers and strain transducers are attached on opposite sides of the pile, near the top, and the signals are led through a combination box to a analyser. Where IPT conducted the instrumentation, this field unit was a Pile Driving Analyzer, described in more detail in Reference (Goble et al, 1980). This unit determines many driving parameters and some of the most interesting are:

(i) Maxima of force, velocity and acceleration;
(ii) The maxima of the transferred energy; and
(iii) The bearing capacity according to the Case Method.

Although the Case Method requires the assumption of a damping factor (Rausche, 1978) and its use is limited due to the simplified formulation, the accumulated offshore experience has demonstrated its good usefulness for field decision--making, now and then.

Concerning to special instrumentation, it should be emphasized the monitoring successfully conducted by Franki/Fugro in the PCH-2 platform in the Cherne field, where was used a MHU 1700 underwater hidraulic hammer. Strain transducers and accelerometers were protected by appropriate waterproof casing as well as the special cables and connectors.

HAMMER PERFORMANCES

Table II shows efficiency values for the several hammers used in all platforms listed in Table I. Here the efficiency is the percentage of the rated energy transferred into the pile (ENTHRU). Some hammers, such as Vulcan 040 and Vulcan 340, were air or steam powered, according to the Contractor. In general the Menck hammers performed well with regular efficiency, while the Vulcan hammers presented a not so uniform

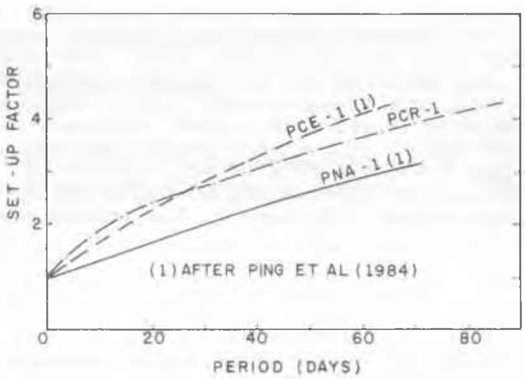

Fig. 3 - Set-Up Trend in Some Fields

Fig. 4 - Microphoto of Specimen from Sample A (x 200).

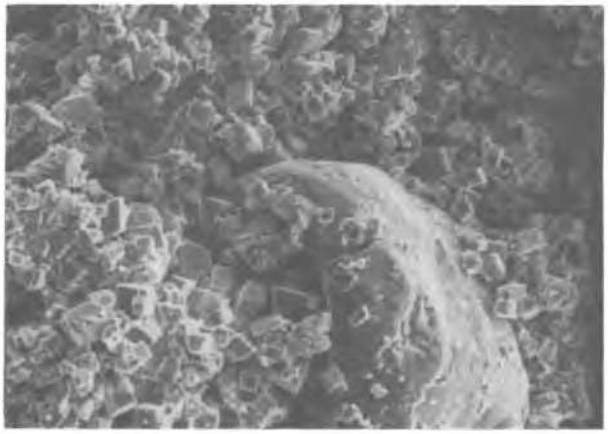

Fig. 5 - Microphoto of Specimen from Sample B (x 300).

performance, i.e., a major range of ENTHRU and the Delmag hammers showed an energy output somewhat less than expected. Some low energy output was observed due to the bad operational conditions, for example, when the compressor was not able to generate proper pressure or even the use of inappropriate cushion capblock. So, those results don't have to be considered as restrictions to the quality of the hammers, but only demonstrate the range of the measured energy.

TABLE II

Transferred Energy of Different Hammers

HAMMER		RANGE OF ENTHRU (kN x m)	RANGE OF EFFICIENCY (%)
VULCAN	020	17 — 65	24 — 78
VULCAN	040	50 — 120	30 — 72
VULCAN	340	30 — 101	18 — 61
VULCAN	560	120 — 320	28 — 66
MENCK	MRBS 3000	190 — 324	42 — 72
MENCK	MRBS 4600	290 — 421	42 — 61
MENCK	MRBS 5000	250 — 465	33 — 62
MENCK	MRBS 7000	220 — 380	26 — 45
MENCK	MRBS 8000	468 — 768	39 — 46
DELMAG	80	59 — 100	28 — 49
DELMAG	30	5 — 15	13 — 17
DELMAG	22/02	17 — 26	25 — 39
MHU	1700	160 — 1005	9 — 59

ASPECTS OF FIELD DECISIONS

In offshore installation, it is unavoidable to take some decisions in the field, for example, with reference to delimitation of the final pile penetration. Normally, CAPWAP analysis is made in the office, on land, very far from the job site. In this situation, due to the high cost of the installation barge, sometimes it is impossible to wait for post-field analysis. This fact would not be a problem if the pile driving responses are in accordance with the design forecast.

Meanwhile, during the installation of PAT-1 and PAT-2 platforms in the Atum field, some surprises were observed. Near the design penetration depth, for some piles the measured bearing capacity evaluated by Case Method were significantly smaller than required. Then, it was decided to proceed with driving, and monitoring all the piles. Considering Case Method, good sense and previous evaluations on damping factor, as well as set-up factor on similar calcareous sand, the bearing capacity of the piles were estimated. This field estimate was made in terms of the tip and skin friction resistances. Subsequent CAPWAP analysis agreed well with field forecast.

Finally, in view of the monitoring results, the initial installation program was modified and the expensive insert-pile solution was avoided.

These examples show how useful is the pile driving instrumentation whenever it is not possible to determine representative geotechnical properties because of the heterogeneity of such carbonate profiles.

CONCLUSIONS

Dynamic instrumentation of driven piles is an usual procedure to control the offshore platform installation in Brazil. So a significant number of 15 offshore piled structures were monitored to date, since 1980.

The instrumentation cost is considered marginal compared to installation cost (de Medeiros Jr., 1983) and doesn't provoke any delay to the piling operation. Consequently, the cost-benefit analysis has completely justified the use of instrumentation.

The information obtained by dynamic measurements in different fields contributed to gain experience on the better understanding of the hammer-pile--soil interaction, specially concerning to calcareous soils.

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